NUCLEAR POWER STATIONS

GEORGE NEWNES LTD

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NUCLEAR POWER STATIONS

General Description. The operation of a nuclear power station depends upon the fact that the heat used to raise steam is derived from a nuclear and not from a chemical reaction. The British nuclear power programme is based on the gas-cooled, graphite-moderated type of reactor, using natural uranium metal as fuel, and it is this type of reactor which is described below.

The heat is generated by the splitting of U^{235} nuclei in the reactor core, which consists of graphite perforated in a regular lattice by a number of channels containing uranium fuel elements. (see Plate, 54, 56). The heat produced in the elements is carried away by a stream of gas (usually carbon dioxide) flowing through each channel. The core is enclosed in a large pressure vessel (24), which is in turn contained within a thick concrete shield (4). The steam-raising units (31) are placed around this; they too are enclosed in pressure vessels (2), which are connected by large-bore ducts (25, 26) to the main reactor vessel, thus forming a number of closed circuits for circulation of the coolant gas, which is maintained by a blower (32) mounted in the cool side of each circuit.

The steam produced in the steam-raising units is led to a turbine hall, where it passes through turbines of more or less conventional design, and the remainder of the station is very similar to a conventional coal-fired station.

Fuel. The fuel used in the type of reactor described above is metallic natural uranium. 0.7% is the fissile isotope U^{235} and the remainder U^{238}, which is not normally fissile. Splitting of a nucleus of U^{235} under neutron bombardment produces a large amount of energy, together with two fission fragments from the original nucleus and several further neutrons. The fission fragments become unstable atoms, whose nuclei undergo radioactive decay until stability is reached. Because of the necessity for containing these radioactive fission products, the fuel rods must be canned. The material used must be fairly transparent to neutrons and magnesium is usually employed.

Reactor Core. The core consists of graphite bricks and is usually cylindrical in form. The central part of the core is the moderator whose function is to slow down the neutrons liberated by fission to speeds in the range of about

2 miles per second, at which they are most likely to be captured by a fissile nucleus, with consequent propagation of the chain reaction. Surrounding the moderator is a layer of graphite two to three feet thick, known as the reflector, which contains no fuel and serves to reflect back into the moderator most of the neutrons which would otherwise escape from it. The problem of preventing loss of neutrons is an extremely important one, since the lack of sufficient neutrons to maintain the chain reaction will halt the working of the reactor.

Reactor Pressure Vessel. Since the coolant gas must circulate under pressure, the entire core must be enclosed in a pressure vessel, which is fabricated from plates 3—4 in. in thickness. As the greater part of the welding must be done on site, this presents the most difficult engineering problem in nuclear power station construction. A spherical shape is usually preferred for the reactor pressure vessel, since for a given plate thickness and pressure a spherical vessel can be built to twice the diameter of a cylindrical one.

Biological Shield. A safety shield of about 9 ft thickness of concrete must enclose the reactor and its pressure vessel entirely, to reduce neutron and gamma currents emanating from the core to safe values for persons working in operating areas. Such large ducts as those for coolant gas are brought out through a series of right-angled bends, in order to attenuate the radiation. Smaller ducts, such as standpipes for access, charging or control purposes, employ ducting of stepped diameters for the same purpose.

Fuel Handling. The main complication here arises from the necessity of remote-controlled operation. Modern designs allow on-load refuelling, and axial change-over of channels, which permits more uniform irradiation of fuel and higher average burn-up. Charging and discharging operations may both be from the top or the bottom, or charge may be from above and discharge from below. Spent fuel is usually transferred to a cooling pond for several months of underwater storage, until short-lived activity has decayed, after which it is loaded into thick cast-iron coffins and transferred to a chemical processing plant.

Coolant Gas Circuit. Carbon dioxide is usually used for the heat transfer circuit, because of its low neutron absorption, chemical compatibility with reactor materials, cheapness and availability. The rate of circulation of the

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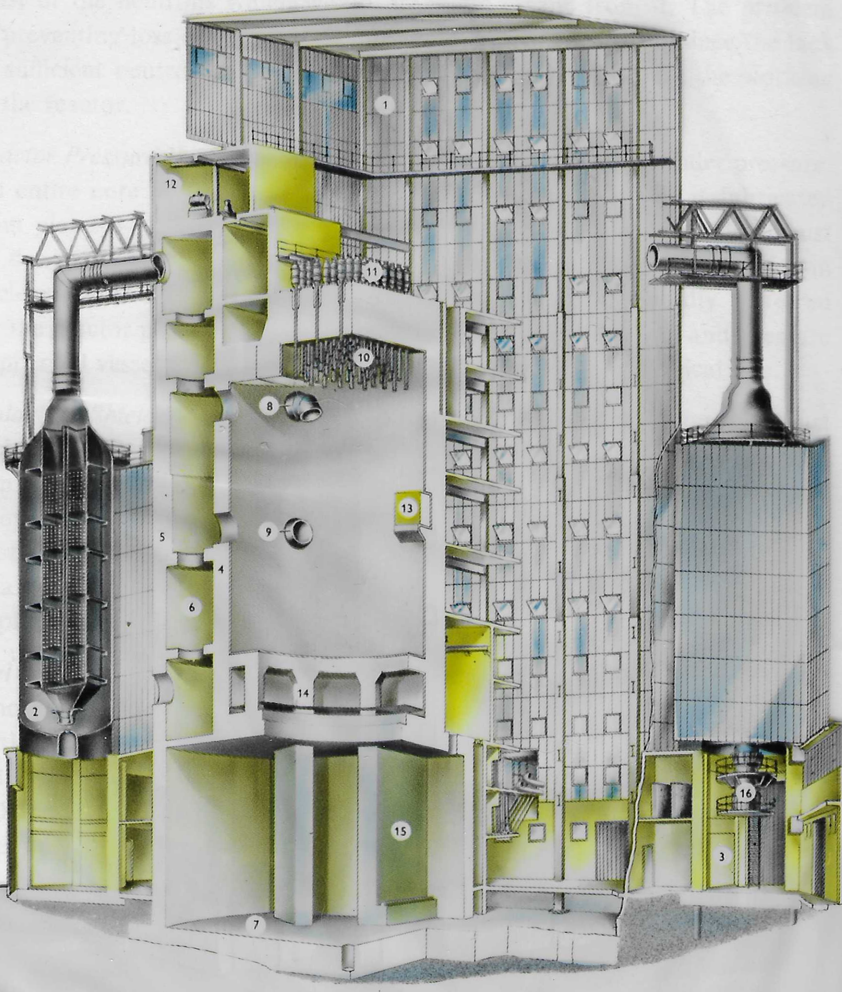
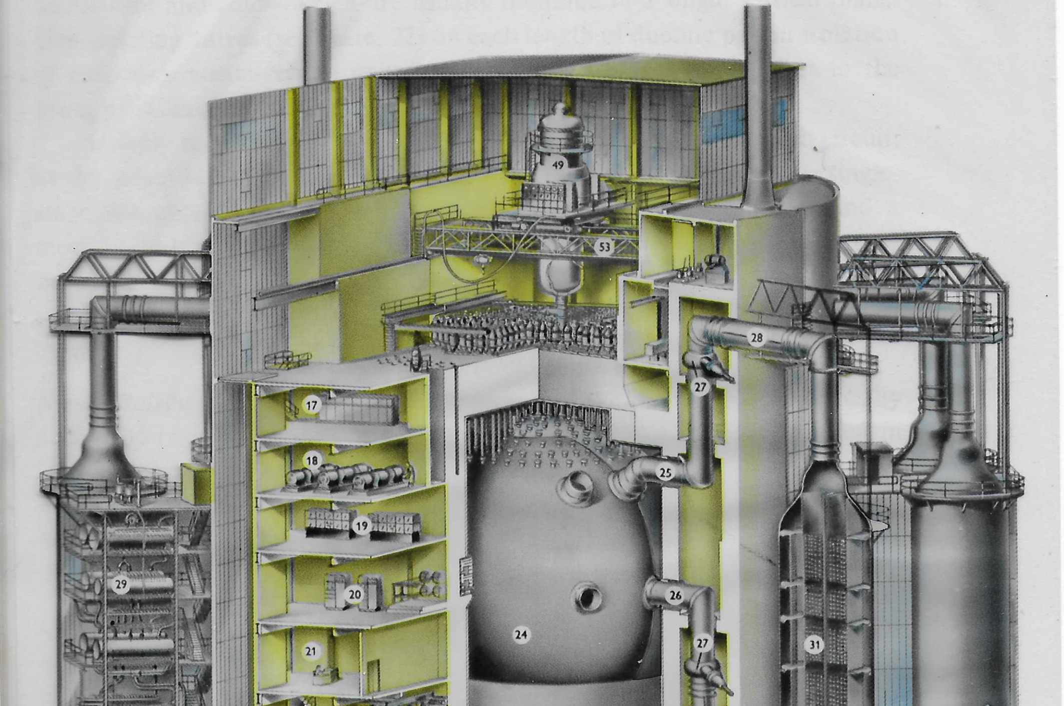
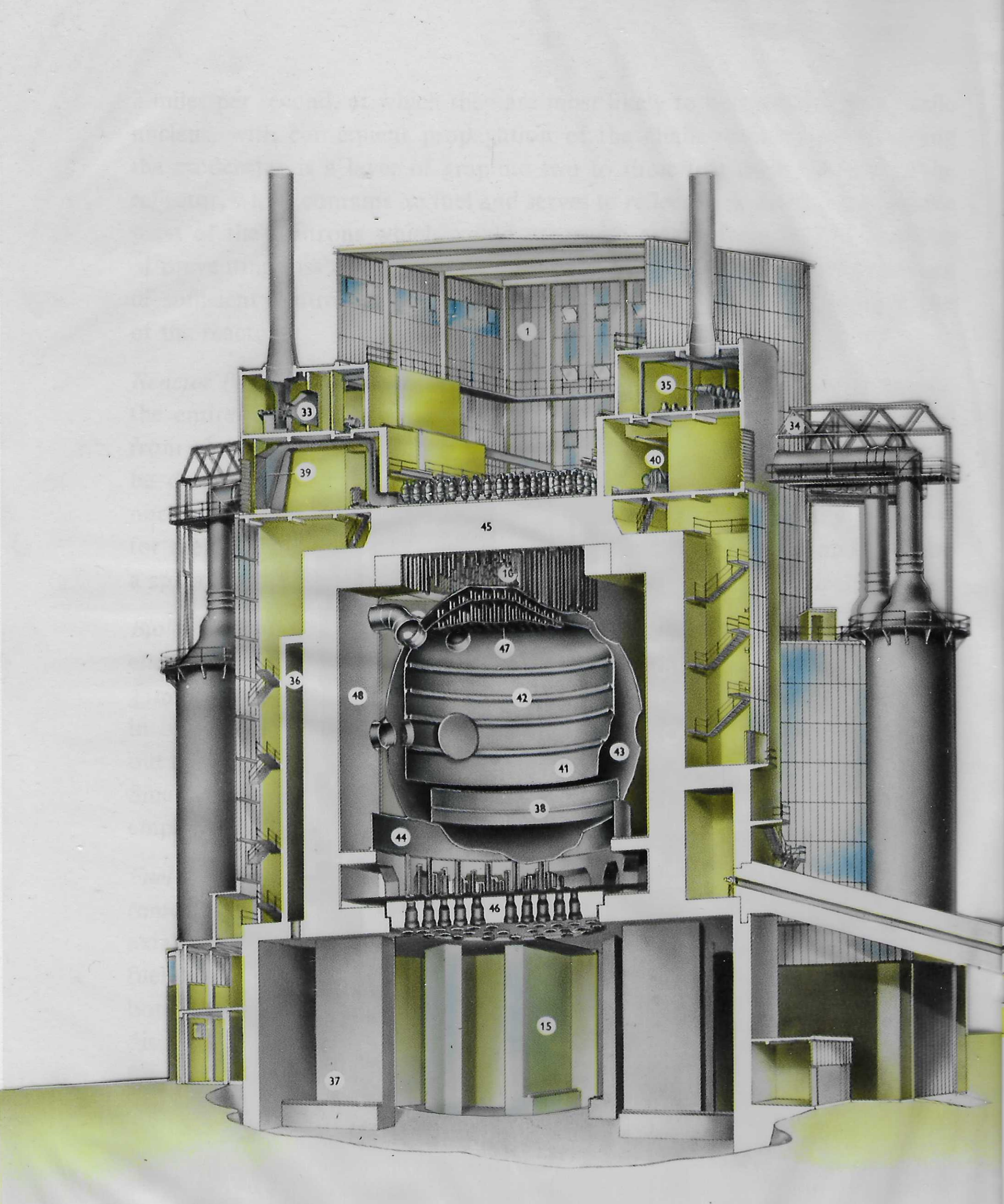


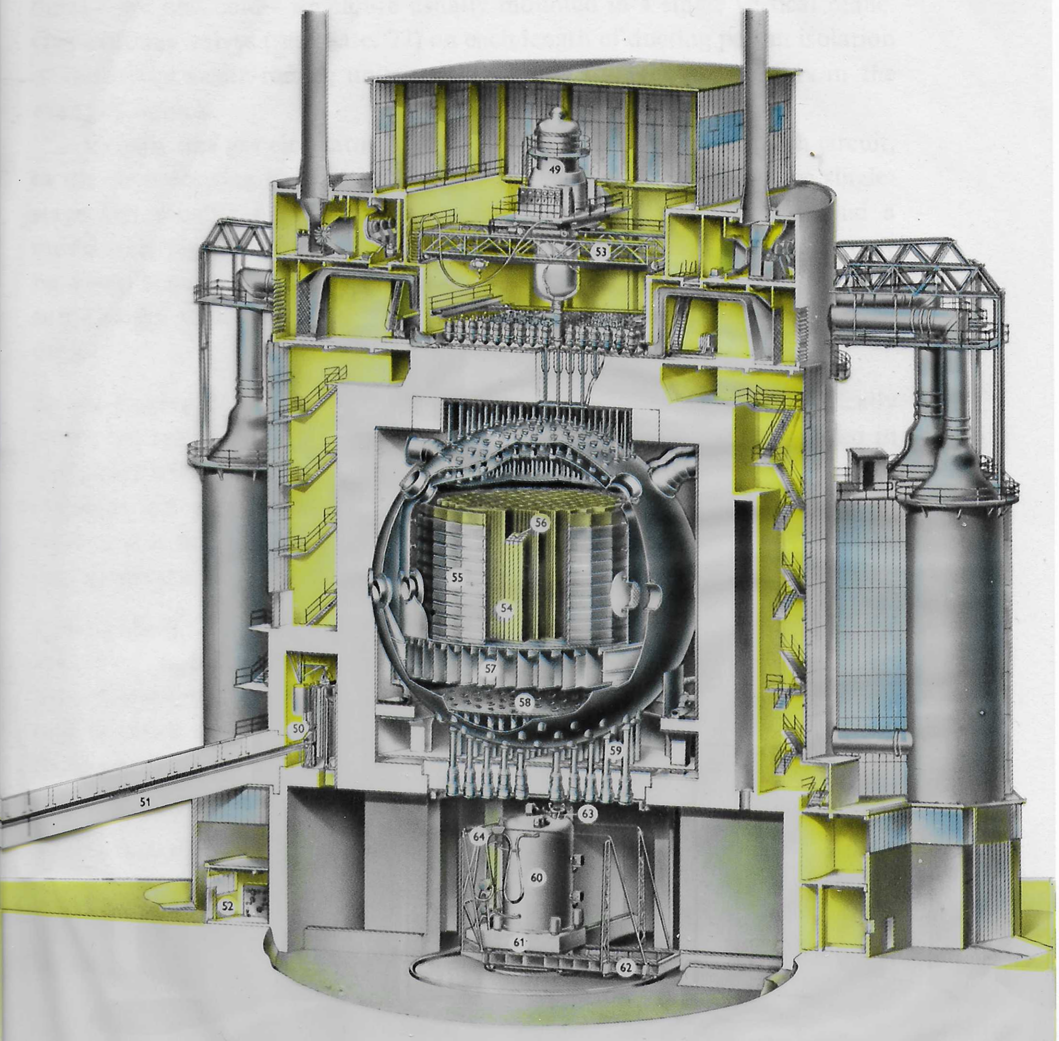
1. **Reactor building**
2. **Steam raising unit pressure vessel**
3. **Steam raising unit sub-structure**
4. **Inner concrete shield**
5. **Outer concrete shield**
6. **Duct chamber**
7. **Charge chamber**
8. **Hot gas duct nozzle**
9. **Cool gas duct nozzle**
10. **Control rod standpipes**
11. **Control rod mechanisms**
12. **B.S.D. precipitator room**
13. **Thermal column**
14. **Pressure vessel support columns**
15. **Main reactor support columns**
16. **Gas circulator motor**



17. B.S.D. control apparatus
18. Control rod motor supply units
19. Switchgear
20. Ion chamber room
21. Charge-discharge control room
22. Charge preparation room
23. Compressor room
24. Spherical pressure vessel
25. Hot gas duct
26. Cool gas duct
27. Gas valves
28. Bellows joints
29. Boiler drums
30. Boiler circulating pumps
31. Steam raising unit tube banks
32. Gas circulator impeller



33. Exhaust fan and chamber
34. Duct support structure
35. B.S.D. precipitators
36. Charge machine test shaft
37. Charge machine test bay
38. Grid support ring
39. Cooling air supply duct
40. B.S.D. cooler
41. Inner steel shell
42. Stiffening rings
43. Pressure vessel interior
44. Steel supporting skirt
45. Upper concrete shield
46. Lower concrete shield
47. Inner shield plate
48. Shield cooling ducts



49. **Reactor servicing machine**
50. **Spent fuel separating room**
51. **Spent fuel conveyor**
52. **Separating control room**
53. **Servicing machine gantry**
54. **Reactor core**
55. **Core restraints**
56. **Fuel channel**
57. **Grid**
58. **Collector pan**
59. **Charge-discharge standpipes**
60. **Charge-discharge machine**
61. **Charge machine carriage**
62. **Charge machine turntable**
63. **Charge machine nozzle**
64. **Charge machine supplies**

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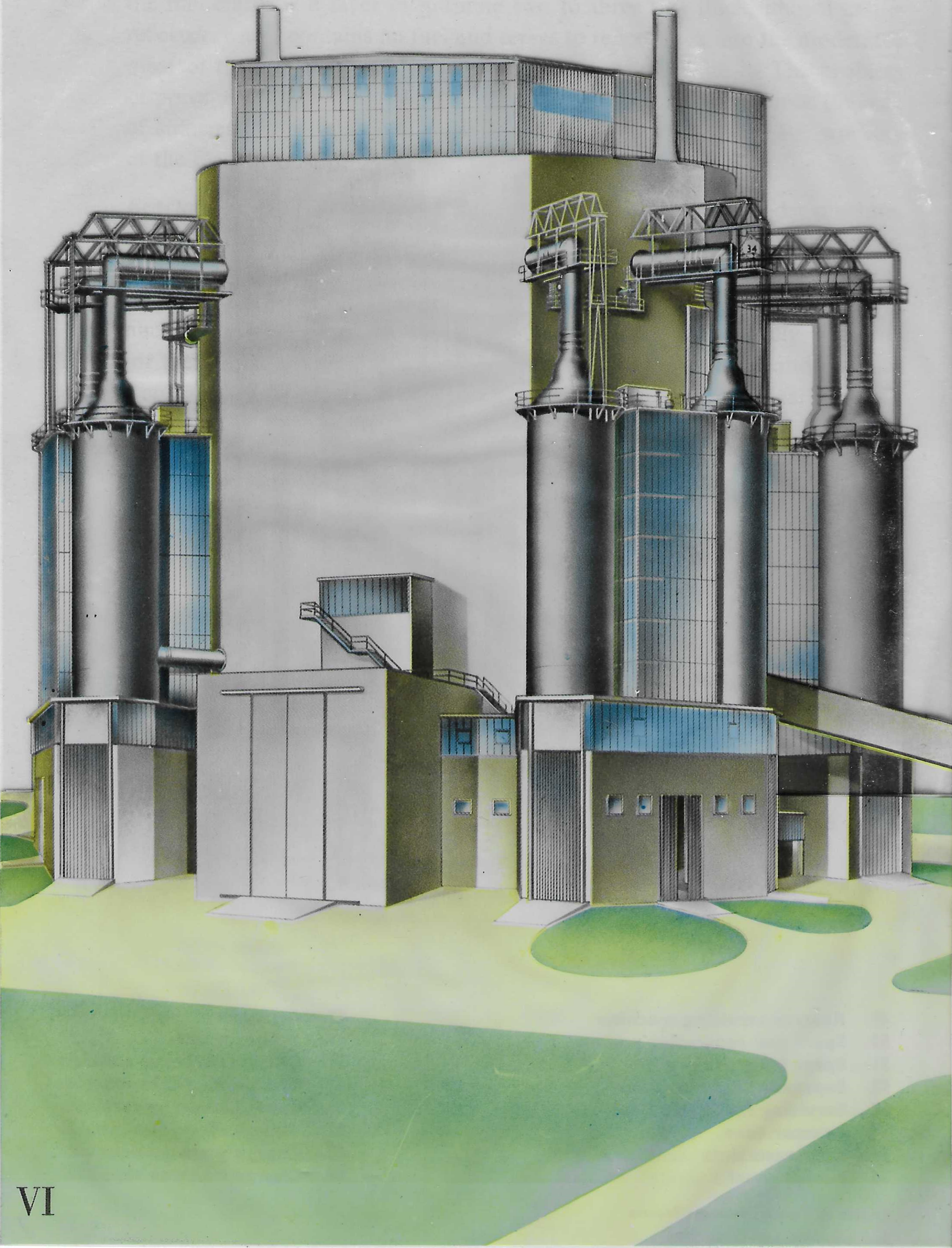

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coolant gas is very high, and thus large gas ducts (*c.* 6 ft diameter) are needed between the reactor and the steam-raising units. Each circuit has a pair of ducts—hot and cold—which are usually mounted in a single vertical plane. Gas isolating valves (see Plate, 27) on each length of ducting permit isolation of individual steam-raising units and their associated gas circulators in the event of failure.

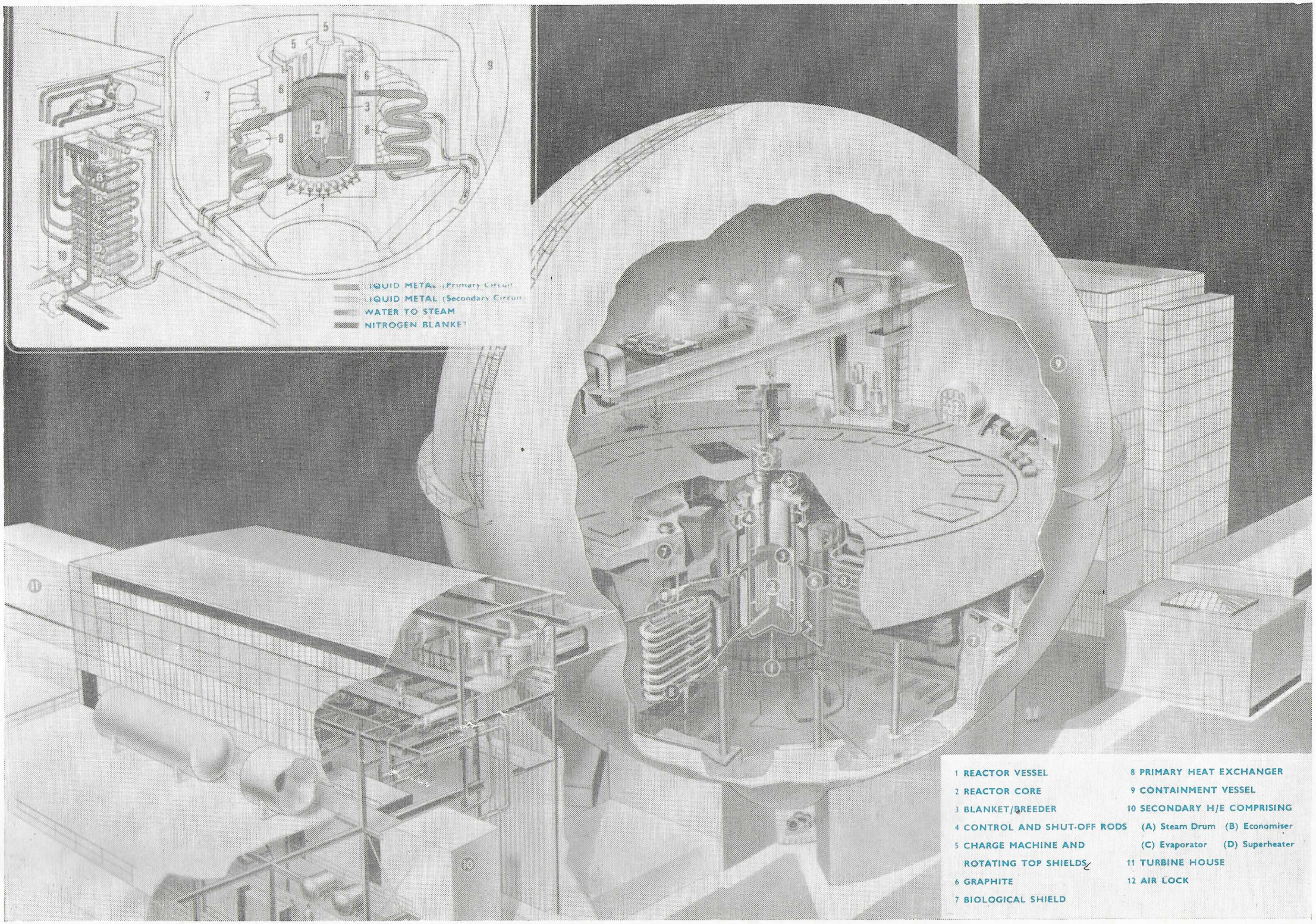
Usually one gas circulator is mounted in the coolest part of each circuit, at the steam-raising unit outlet. The gas blower is essentially a large single-stage fan capable of handling carbon dioxide at a high pressure and a moderately high temperature. Either centrifugal or axial-flow impellers may be used, according to design requirements. Gas circulator drives may be supplied by various forms of a.c. or d.c. motor, or by direct steam-turbine drive.

Steam-Raising Plant. 4, 6 or 8 steam-raising units are placed symmetrically about the reactor. Since their heat-transfer surfaces have to be enclosed in a pressure vessel, space saving is essential. As in addition the gas temperatures involved are much below the temperatures encountered in conventional boilers, it is necessary to design for a very low minimum difference between the temperatures of the water/steam and gas sides.

Control Rods. The rate of reaction is controlled by inserting rods of neutron-absorbing material into the core. Boron, in the form of boron steel rods, is usually employed. The rods are suspended from above the reactor and lowered into channels of the core as required. In an emergency the power supply to the activating mechanism is cut, and the control rods fall into place by gravity.

Plant Control. Output of the plant may be determined from either the reactor or the turbine end. Thus the power level may be set at the reactor, with the turbines taking all the steam produced, or alternatively, the reactor may be automatically controlled to produce the desired amount of steam for a given turbine setting.

Safety. Safety is of paramount importance in designing nuclear reactors. All equipment must be completely reliable; in particular, it is essential that mechanism for inserting control rods should function with absolute certainty, and the continuity of gas flow must be guaranteed.


LIQUID METAL (Primary Circuit)
LIQUID METAL (Secondary Circuit)
WATER TO STEAM
NITROGEN BLANKET
1 REACTOR VESSEL
2 REACTOR CORE
3 BLANKET/BREEDER
4 CONTROL AND SHUT-OFF RODS
5 CHARGE MACHINE AND ROTATING TOP SHIELDS
6 GRAPHITE
7 BIOLOGICAL SHIELD
8 PRIMARY HEAT EXCHANGER
9 CONTAINMENT VESSEL
10 SECONDARY H/E COMPRISING
(A) Steam Drum (B) Economiser
(C) Evaporator (D) Superheater
11 TURBINE HOUSE
12 AIR LOCK

DOUNREAY REACTOR

A REACTOR of a different type from that described earlier is illustrated in diagrammatic form on the facing page. This depicts a large-scale experimental reactor installed at the U.K.A.E.A. Industrial Group's research and development establishment at Dounreay, Caithness. The reactor shown is a fast fission breeder reactor which produces 60 MW of heat in a core no bigger than a dustbin. Pure fissile fuel is used. The rods are niobium clad and housed in a hexagonal graphite core, which is surrounded by a blanket of natural uranium, the whole being contained within a stainless steel pressurised double-walled tank. Fertile material is converted in the breeder blanket into new fuel at a rate exceeding that at which fissile material is burnt. The coolant used is liquid sodium, circulated in primary and secondary cooling circuits by electromagnetic liquid metal pumps. The heat collected from the core is transferred in the 24 primary heat exchangers to a secondary heat exchanger, which transfers it to pure water, which in turn is converted into steam. The steam may be used to drive turbo-alternators, or may be recondensed by sea water and returned for further use. Shielding is in the form of borated graphite, enclosed in concrete, and the whole is contained within a steel sphere 135 ft in diameter.

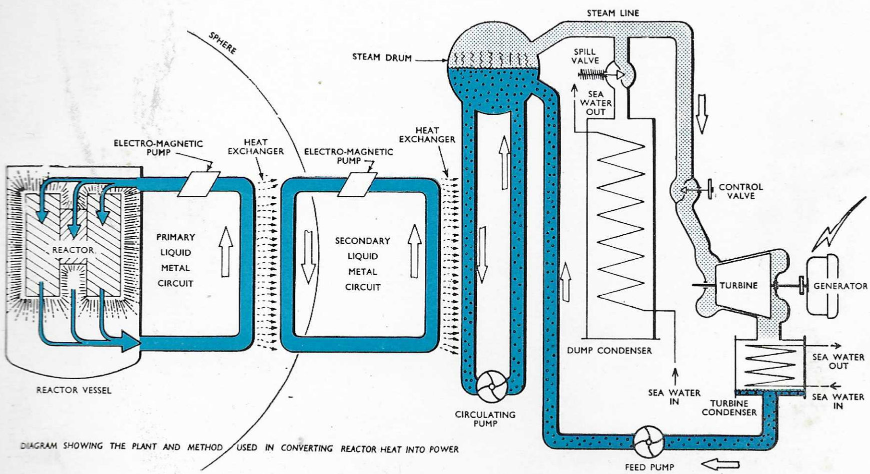


DIAGRAM SHOWING THE PLANT AND METHOD USED IN CONVERTING REACTOR HEAT INTO POWER

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